MODELING HYDROLOGIC RESPONSES TO DEFORESTATION/FORESTATION AND CLIMATE CHANGE AT MULTIPLE SCALES IN THE SOUTHERN US AND CHINA

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Introduction

Watershed management and restoration practices require a clear understanding of the basic eco-hydrologic processes and ecosystem responses to disturbances at multiple scales (Bruijnzeel, 2004; Scott et al., 2005). Worldwide century-long forest hydrologic research has documented that deforestation and forestation (i.e. reforestation and afforestation) can have variable impacts on watershed hydrology (Andreassian, 2004). Such impacts can be amplified by the current global climate change that results in increased air temperature and intensified precipitation. Uncertainty, speculations, and debates on the roles of forests in regulating water resources remain (Bruijnzeel, 2004; Robinsons et al. 2003). Eco-hydrologic studies are especially urgent in regions such as northern China where water stress has been severe and sciences are lacking in guiding the current large-scale vegetation-based watershed restoration campaigns (Sun et al 2006). Conflicts of human water demand and water needs by ecosystems are expected to increase dramatically in the near future due to human population growth, climate change, groundwater degradation and depletion, and increased food and fiber production demands (Sun et al. 2005). Watershed management policymaking is becoming more complex and extremely challenging given the many constrains on water and other ecosystem services that a watershed is required to offer (e.g. soil erosion control, carbon sequestration, habitat) (Jackson et al. 2005).

To understand the hydrologic responses to a changing environment, a process-based research approach is needed. The traditional 'paired watershed' black-box approach has been well accepted around the world as the best way and scale to study the effects of land management practices (Brown et al. 2005). Hydrologic modeling can be viewed as a complementary tool to this traditional approach, and provides an alternative cost-effective method in process-based hydrologic research. Hydrologic modeling is perhaps the only way to extrapolate small watershed-scale experimental findings to basin and the region scales.

The objectives of this paper were: (1) to present application examples of a series of eco-hydrologic models in quantifying the hydrologic effects of land management and climate change on water yield at multiple spatial and temporal scales; (2) demonstrate the unique roles of modeling in hydrologic research, and (3) to identify research needs of model development for predicting hydrologic effects of forestation and climate change on water resources.

Methodology

We have applied several mathematical models in the southern US and China to study forest hydrologic processes and effects of disturbances on the processes at multiple scales (Table 1). Those models vary in complexity because they were developed with different objectives. Consequently, they differ in structure, scale, utilities, and climatic driver and parameter requirements to run them. The model scales vary from a sub-daily to an annual. They have been applied to a variety of landscapes, from humid forested wetlands on the Atlantic coastal plains in the southeastern U.S. to the semi-arid Loess Plateau in Northwestern China, and from a small watershed scale (12 ha) in the Appalachian moutons to the entire Mainland China. References are list to provide readers with detailed information on the model applications.

Table 1. A list of models applied to the southern US region and China

Model	Objectives	Key features	Key References
MIKE SHE	Simulating effects of landuse and climate change effects on watershed hydrology	-Process based, fully distributed -Describes full hydrologic cycle -Integrated surface water–groundwater flow -GIS use interface -Sub-daily temporal scale	Lu, 2006
PnET	Simulating forest ecosystem process (C, N water cycles); Effects of climate change and air pollution on forest productivity and water yield, N leaching	-Process based, stand-scale, but applied to a regional scale -Describes full C, N, and water cycles -Easy to use -Daily to monthly temporal scale	McNulty et al. 1996 Sun et al 2000
MRSWARM	Simulating regional effects of landuse change, climate change, population growth on water yield	-Simple water bucket model for regional application -Evapotranspiration is key for water balance modeling -Monthly temporal scale	New development
Annual evapotransp-iration (ET) model	Annual evapotranspiration, water yield	-Simple function of potential ET, precipitation, and plant water use factor -Annual temporal scale	Zhang et al., 2001 Sun et al. 2005 Sun et al. 2006

Results and Discussion

The MIKE SHE model was tested with forest hydrologic data from four research sites that represent pine flatwoods, natural and drained coastal plains, and Appalachian mountain uplands in the southeastern US (Lu, 2006). We concluded that the model describes the flow generation mechanisms of the diverse study watersheds adequately (Lu, 2006). The modeling studies confirmed that saturated overland flow dominates the low gradient coastal watershed while rapid subsurface groundwater flow contributes to mountain stream flow during storm events. Results suggest that the saturated variable sources area in a typical coastal watershed can be relatively large while it may be quite small in the steep upland watershed. Model applications suggest that reduction of leaf area index would increase streamflow in forested watersheds, and raise groundwater table depth in wetlands. These effects are mostly pronounced during dry periods. An increase in air temperature by 2 °C and a reduction of precipitation by 20% would impact streamflow significantly, especially in the coastal plain regions that have higher evapotranspiration, but lower total annual precipitation with higher variability when compared to the mountain watersheds. The model is being evaluated for the watersheds on the Loess Plateau (Tianshui Soil and Water Conservation Station, Gansu Province) and southern China (Dinghu Mountain Natural Reserve, Guangdong Province) (See paper by S.Wang this volume).

The PnET model, developed originally for northern hardwood forests, has been parameterized and validated against measured forest productivity and hydrology data at the stand scale for both southern pines (Loblolly pine on wetland) and hardwoods (Oak on uplands) (Sun et al, 2000; Hanson et al. 2004). It was further modified and evaluated at the regional scale (McNulty et al., 1996) to examine climate change impacts on water yield, forest productivity, fuel loads, and timber prices in the southern US region. In addition, this model was integrated with soil a biogeochemical model (Forest-DNDC) to simulated detailed C, N, and water cycles at the field and small watershed scale (Sun et al., 2006).

The MSWARM (Monthly Simulator for WAter Resources Management) system integrates a monthly water budget model and projections of future climate change, landuse change, population dynamics, and groundwater supply (Sun et al., 2005). This system was used to examine the spatial and temporal distribution of water stress defined as the ratio of water supply from surface and groundwater sources and water demands by economic sectors including irrigation agriculture, thermoelectric power plants, commercial, and domestic users. We found that climate change is the most important driver for future regional water stress while groundwater supply is critical to groundwater-dependent regions irregardless of changes of climate and change.

The annual ET model developed by Zhang et al. (2001) was applied to southern US and continental China to examine potential annual water yield response to deforestation (Sun et al., 2005) and forestation (Sun et al., 2006). The modeling study suggests that deforestation can result in an increase of water yield by 50-400 mm/yr in the southern US which has diverse forests, climate, and topographic conditions. Model application indicates that forestation has potential to decrease water yield by 50 mm/year (or 50%) in the semi-arid Loess Plateau region in northern China to about 300 mm/year (30%) in the tropical southern region.

Our collaborative studies conclude that hydrologic processes differ across landscapes, climate, and landuse conditions. Therefore, we predict that hydrologic responses to deforestation/forestation will vary across the complex gradients. Mechanisms of hydrologic response to changes in climate and land covers need to be incorporated to the existing models. We also stress the importance of physical-biological interactions in forest hydrologic modeling under a changing environment.

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